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Anomalous Growth and Reproductive Patterns in Populations of *Chaetodon miliaris* (Pisces, Chaetodontidae) from Kaneohe Bay, Oahu, Hawaiian Islands[1]

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ABSTRACT: Specimens of *Chaetodon miliaris* collected in Kaneohe Bay, Oahu, during a 15-month study appeared to be reproductively inactive and were smaller than were those from other Hawaiian study areas. Additionally, they lacked calanoid copepods in their diet, the main food consumed elsewhere. It is suggested that the absence of this food in their diet resulted in a dietary deficiency leading to poor growth and reproductive inactivity.

RECENT STUDIES have revealed the impact of man's activities on the water quality and community structure of the Kaneohe Bay ecosystem (Cox et al. 1973; Smith, Chave, and Kam 1973), but studies demonstrating more subtle effects on reef fish populations have been lacking. In particular, studies on the physiological ecology of reef fishes can help to explain observed variations in the structure and composition of the bay ecosystem.

In this study an attempt has been made to explain certain anomalous characteristics of Kaneohe Bay populations of the millet-seed butterflyfish, *Chaetodon miliaris*, on a physiological or dietary basis. A recent study of this fish has examined aspects of its growth, reproduction, and diet (Ralston 1975), and the results reported herein are a portion of that work. *Chaetodon miliaris* is an abundant Hawaiian endemic fish (Gosline and Brock 1960) that feeds primarily in the water column on planktonic crustacea, principally calanoid copepods (Hobson 1974, Ralston 1975). Changes in the community structure of the zooplankton within the bay, such as those documented by Clutter (1973), are directly reflected in the diet of this fish and afford an opportunity to study the transmission of stress through the food chain.

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MATERIALS AND METHODS

Sixty collections comprising 345 individuals of *Chaetodon miliaris* were sampled at various localities around the islands of Oahu and Hawaii between January 1974 and April 1975. Of these, 115 individuals in 12 collections were sampled from Kaneohe Bay. These 115 fish were collected at five different study sites within the bay (Figure 1). All fish were collected by spearing with either a pole spear or a "microspear" (Randall 1963).

Fish were injected intraperitoneally with a solution of 10-percent buffered Formalin in the field to prevent deterioration of food materials in the gut. Fish were then placed in a bath of similar solution for final preservation. After each fish had been preserved, its standard length, total length, body depth (all to the nearest millimeter), and wet weight (to the nearest hundredth of a gram) were determined (Hubbs and Lagler 1947).

Gonads were excised from all fish and were

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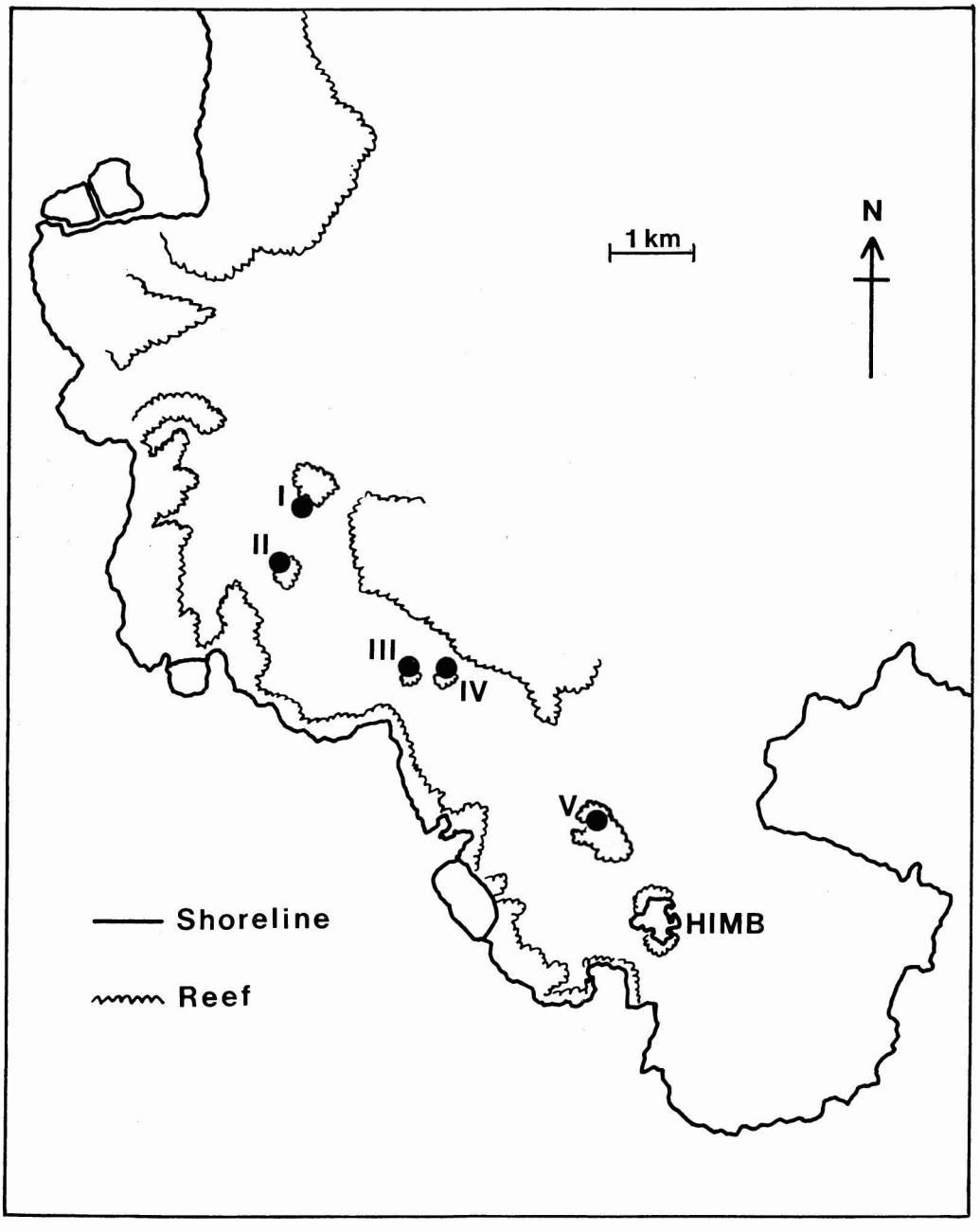

FIGURE 1. Locations of collecting sites in Kaneohe Bay. HIMB, Hawaii Institute of Marine Biology.

wet-weighed to the nearest .0001 g after excess moisture had been removed. Individual fish were classified as either male, female, or immature by microscopic examination of gonadal material. If neither oocytes nor spermatozoa or seminiferous tubules were recognizable, fish were considered immature. After gonads were weighed and sexed, the ovaries were staged according to an abbreviated form of Kesteven's (1960) classification. In this system, ovaries are

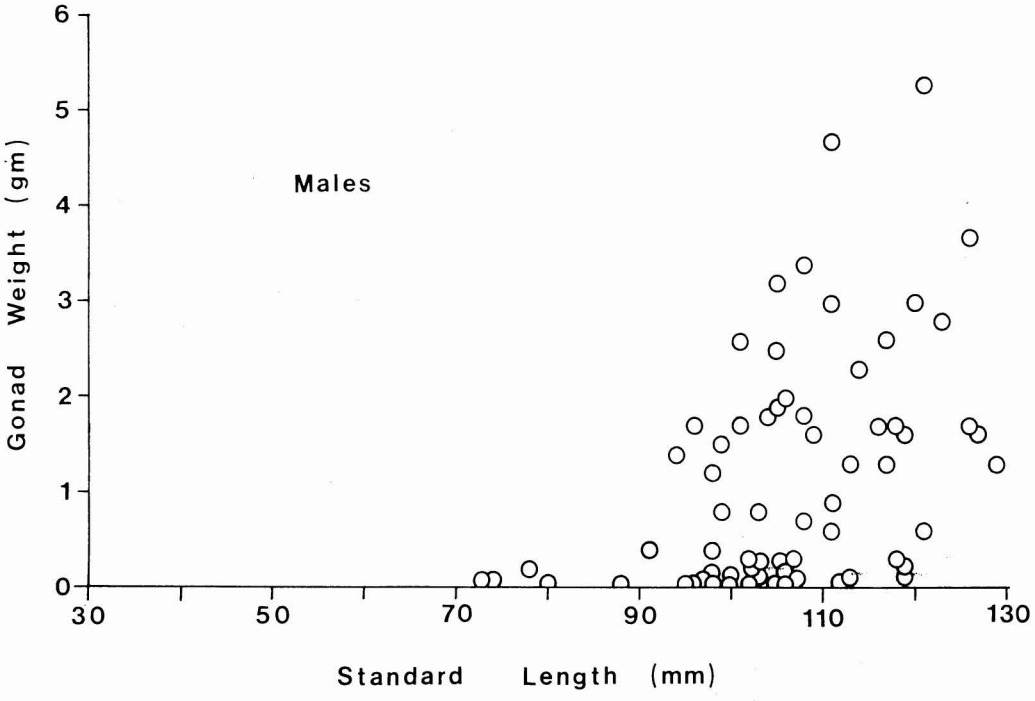

FIGURE 2. Testicular weight as a function of size of *Chaetodon miliaris*. Data for all males collected during the spawning season, November–May. $N = 67$.

recognized as "virgin," "developing," "gravid," or "spawning".

Feeding habits of individual fish were quantified in the following manner. The stomach was removed from the fish and stored in 10-percent buffered Formalin until examined. During examination, the stomach was slit open and the contents washed into a Petri dish. The food material was teased apart under a dissecting microsope and a list of all food types present was compiled. Once the list of food items was completed, visual estimates of the percentage of total food present by volume were made for each food type. The technique is similar to that used by Hobson (1974).

RESULTS

Size at which reproduction commences can be estimated by examining the relationship between standard length (SL) and gonad weight. The testicular weights of all males collected during the spawning season, which lasts from November through May (Ralston 1975), are plotted as a function of size in Figure 2. Reproductive activity appears to commence at a length of about 90 mm SL, at which time testicular weight shows an abrupt increase. Similarly, the weights of all gravid or spawning ovaries are plotted as a function of size (Figure 3), indicating that female *C. miliaris* reach reproductive maturity at the same size as do males. Ralston (1975) has shown there is reason to believe that the growth rates of male and female *Chaetodon miliaris* are the same with both sexes maturing after 1 year of growth.

Size-frequency distributions of individuals collected in Kaneohe Bay and those collected elsewhere are given in Figure 4. *Chaetodon miliaris* collected in Kaneohe Bay were significantly smaller than those collected in other areas ($t = 27.8$, $df = 343$, $P \ll .001$) (Snedecor and Cochran 1967). Of 115 individuals collected in Kaneohe Bay, only eight fish, or about 7 percent of the population, were greater than 90 mm SL, the estimated size at first reproduction. Examination of the gonads of fish from the bay showed that no fish was collected in which the gonad

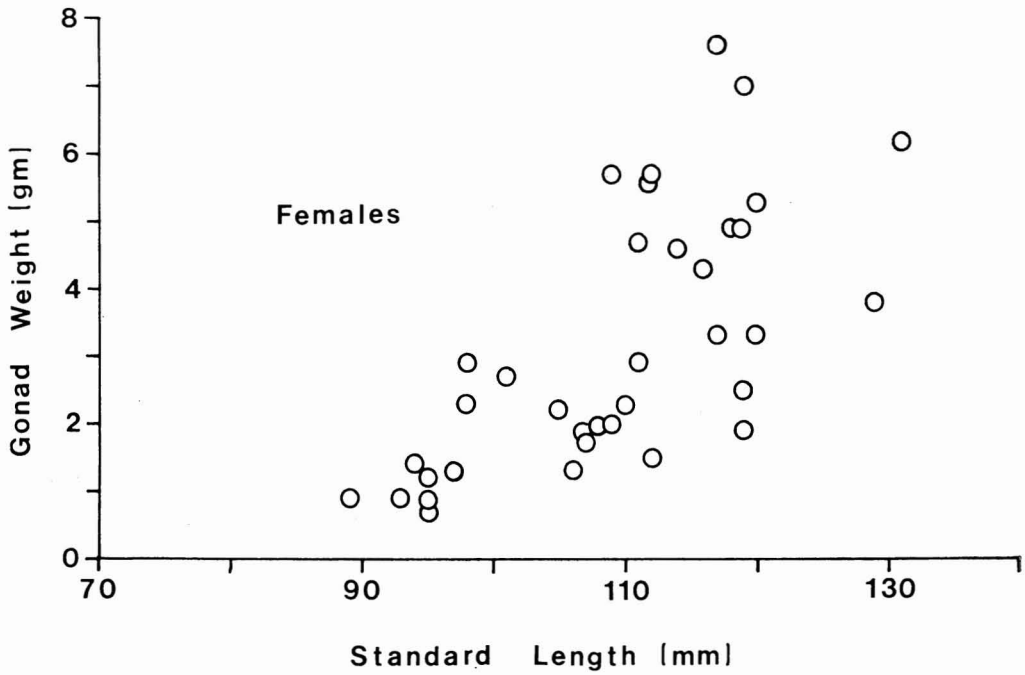

FIGURE 3. Ovarian weight as a function of the size of either gravid or spawning *Chaetodon miliaris*. $N = 36$.

TABLE 1

COLLECTION INFORMATION FOR *Chaetodon miliaris* TAKEN WITHIN KANEOHE BAY

SITE NUMBER	NAME	NUMBER OF FISH COLLECTED	MEAN SIZE, STANDARD LENGTH (mm)
I	Buoy 13	22	71.9
II	Buoy 15	74	69.7
III	–	4	101.5
IV	Wass's Reef	9	64.7
V	Checker Reef	6	68.8
Total		115	$\overline{X} = 70.4$

weight was more than 0.25 percent of the body weight, a figure indicating little or no spawning activity (Ralston 1975). A summary of size information for fish collected at each of the five Kaneohe collecting sites is given in Table 1.

Comparisons of diet were made between fish collected at Waikiki, Kaneohe Bay, and the Waianae coast of Oahu by a quantification of the gut contents of 10 fish from each area. All 30 fish were collected in April 1975 and were of a similar size. Comparisons were made of the four main items in the diet of *C. miliaris*: calanoid copepods, assorted eggs, algae, and larvaceans (*Oikopleura* sp.) (Ralston 1975). The results of four Kruskal-Wallace H tests (Tate and Clelland 1957) run on each of these food categories are given in Figure 5. There are no significant differences in the relative contributions that eggs make to the diets of *C. miliaris* collected in Waikiki, Kaneohe Bay, and the Waianae coast. On the other hand, both calanoid copepods and larvaceans show very significant differences in their relative contributions to the diets of fish from these areas ($P \ll .005$ and $P < .005$,

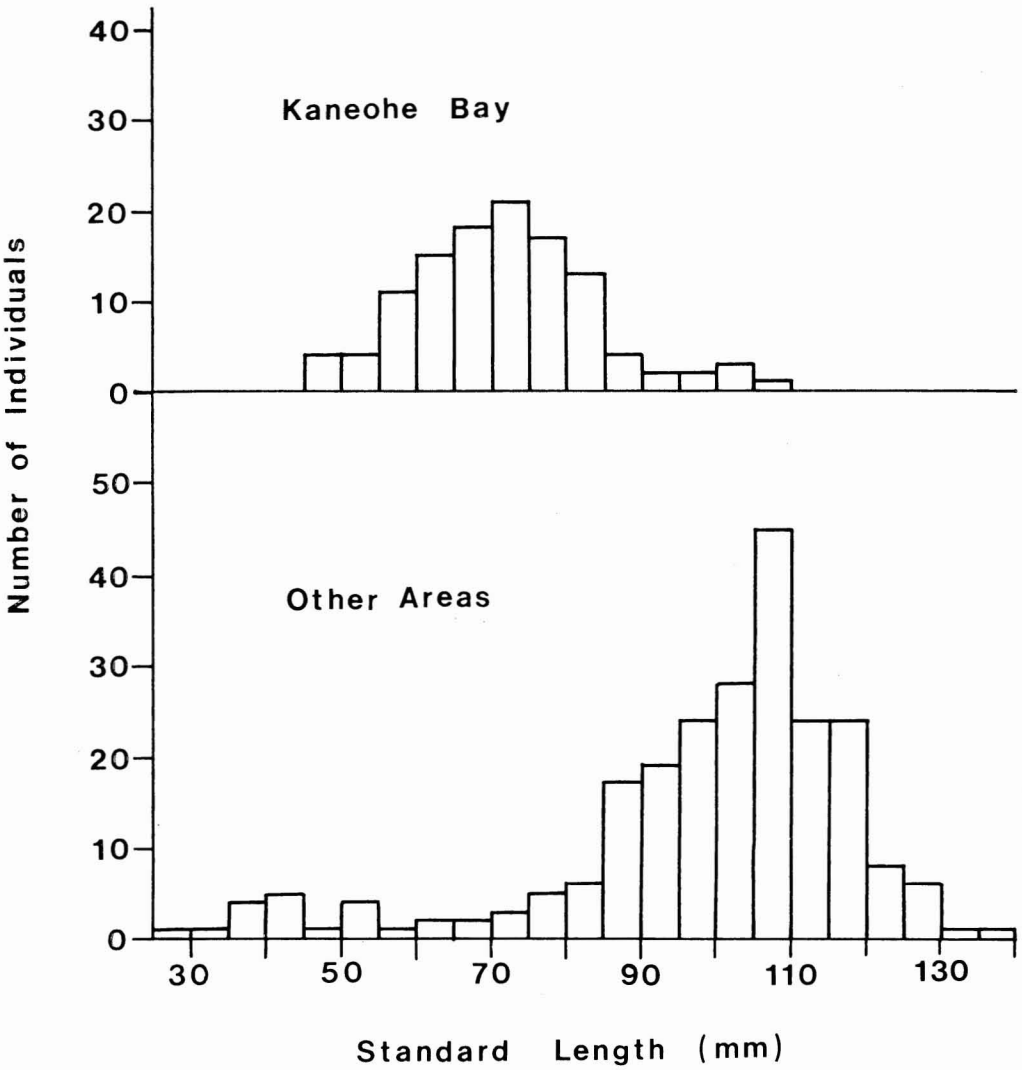

FIGURE 4. Size-frequency distributions for *Chaetodon miliaris* collected in Kaneohe Bay and elsewhere.

respectively). Calanoid copepods are the single most important item in the diet of *Chaetodon miliaris* in most areas (Hobson 1974, Ralston 1975), but they were found to be absent in the diet of fish collected in Kaneohe Bay. The diet of the Kaneohe Bay fish is characterized by relatively large contributions of both larvaceans and algae.

DISCUSSION

Populations of the millet-seed butterflyfish in Kaneohe Bay have been shown to be smaller than those sampled elsewhere. Additionally, individuals in the bay appear to be reproductively inactive and to feed on types of food not typical of other Oahu populations. Watson and Leis (1974) reported the complete absence of chaetodontid eggs and larvae in Kaneohe Bay. They attributed this absence to a possible migration of spawning adults out of the bay and to the existence of the specialized pelagic prejuvenile tholichthys stage characteristic of this group.

A comparison of the results of the present

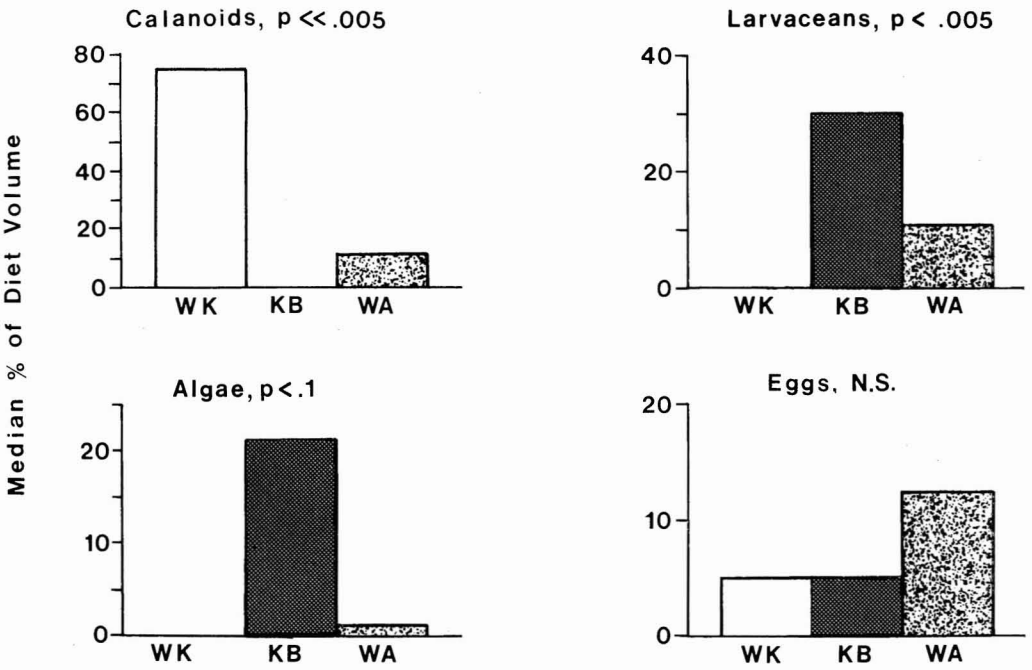

FIGURE 5. Contributions to the diet of *Chaetodon miliaris* by the four major food categories at each of three different collection localities. WK, Waikiki; KB, Kaneohe Bay; WA, Waianae coast.

investigation with those of an earlier study by Wass (1967) indicated that demographic changes have occurred recently in populations of *C. miliaris* in Kaneohe Bay. Using rotenone, Wass collected all fishes from a small patch reef in the bay. Included in his sample were 476 *C. miliaris*. He calculated the size-frequency distribution for these fish and this distribution is reproduced in Figure 6. There are two modes in this curve which are located at 7 and 12 cm total length. These correspond respectively to 5.8 and 10.5 cm standard length (Ralston 1975). The absence in recent years of the second, larger mode (cf. Figure 4) indicates the loss of larger individuals from the bay since the time of Wass's study.

A parallel phenomenon has been reported for another species of fish in Kaneohe Bay. Stevenson (1963) reported that specimens of *Dascyllus albisella* (Pomacentridae) captured in Kaneohe Bay were significantly smaller than those taken at Waikiki. Additionally, he found no mature ovaries in specimens taken from Kaneohe Bay, even during the height of spawning season. The primary foods of *D. albisella* were reported to be copepods and larvaceans as well (Stevenson 1963), although diet was not analyzed by locale. Possibly these two food items were consumed in different quantities at Waikiki and Kaneohe. Stevenson speculated that the absence of reproductively active *D. albisella* from the bay was due to a minimum depth at which spawning could occur. The shallowest depth at which he observed spawning at Waikiki was 40 feet, but most of the reef habitat within Kaneohe Bay lies above this depth (Smith, Chave, and Kam 1973). However, the distinct change in the size-frequency distribution of *Chaetodon miliaris* since 1967 suggests that some other factor besides depth significantly affects these fish, as the depth profile of the bay presumably has not changed radically since that time. On the other hand, the atypical diet of *C. miliaris* is apt to be a more recent development (see below).

Clutter (1973) has documented some of the changes that have occurred to the planktonic community in the bay as a result of human-induced stress. In particular, he found a decrease in the standing crop of macrocopepods with time.

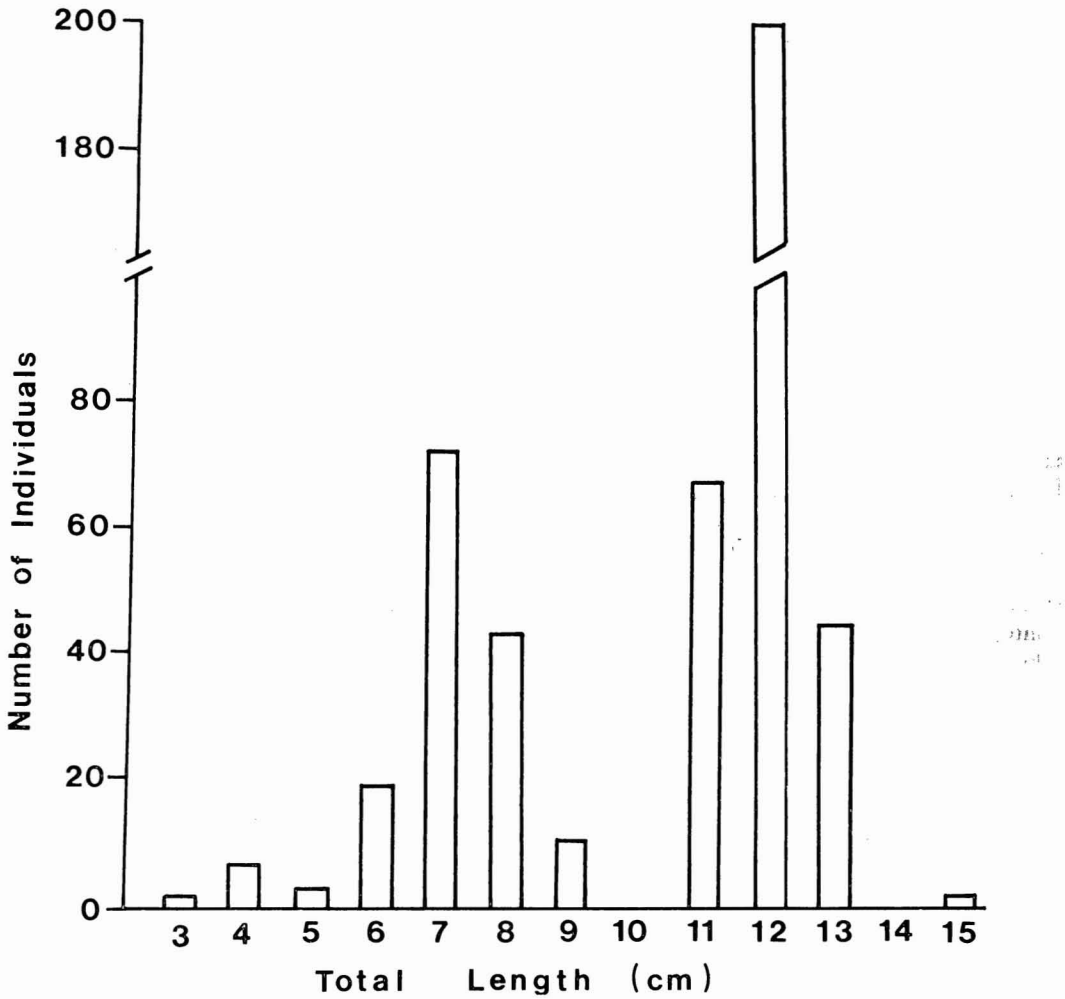

FIGURE 6. Size-frequency distribution of *Chaetodon miliaris* collected by Wass (1967) in Kaneohe Bay. (Figure has been redrawn from his figure 7.)

A high lipid content (up to 65 percent dry weight) has been associated with certain species of copepods (Lee, Hirota, and Barnett 1971; Benson and Lee 1975). This lipid fraction is divisible into wax and oil components. It may be speculated that the absence of copepods in the diet of *C. miliaris* in Kaneohe Bay might lead to deficiencies in certain key lipids that are necessary for normal reproductive maturation and growth.

In support of this speculation, it has been found that certain lipids (e.g., linolenic series [ω 3] fatty acids) are essential dietary requirements for some freshwater fishes (National Academy of Sciences 1973). Additionally, Cowey and Sargent (1972) have shown that internal fluctuations in the fatty acid composition of certain lipid classes are associated with environmental changes and that the single largest environmental factor affecting internal fatty acid composition in fishes is the diet. Finally, Love (1970) has demonstrated that maturation in salmon is accompanied by extensive depletion of lipid reserves in the flesh and that some of the lipid thus liberated finds its way to the gonads.

In contrast to this hypothesis, Craig MacDonald (personal communication) has observed

Abudefduf abdominalis, a pomacentrid fish like *Dascyllus albisella*, spawning at several localities in the bay. Helfrich (1958) showed that in the past this fish fed extensively on calanoid copepods in Kaneohe Bay, although it is not clear that individuals presently in the bay feed on them in view of Clutter's (1973) findings that the abundance of macrocopepods within this ecosystem has declined in recent years. Nor is it known whether the spawnings of *Abudefduf abdominalis* are less frequent occurrences now than in the past or whether the viability of eggs has suffered.

Larvaceans largely replace copepods in the diet of *Chaetodon miliaris* from Kaneohe Bay. The size of the lipid fraction in larvaceans is not known, although it is probably smaller than that of the copepods found in the stomachs of *C. miliaris* from other collection localities (Jed Hirota, personal communication). Further studies are needed not only to assay the lipid content of larvaceans but also to investigate whether or not endogenous alterations to the physiology of *C. miliaris* in Kaneohe Bay have occurred. Such alterations may be based on differences in the consumption of lipids between the bay and other localities; however, differences in the vitamin, protein, or caloric content of the foodstuffs should not be overlooked as potential causes of the anomalous attributes of populations of *C. miliaris* in Kaneohe Bay.

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